The Exotics and Cosmic Ray Physics Program of NOvA

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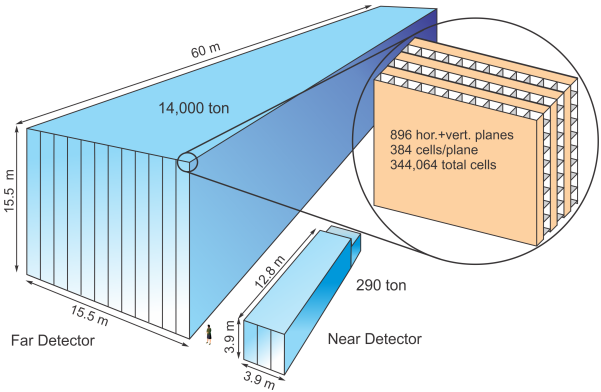
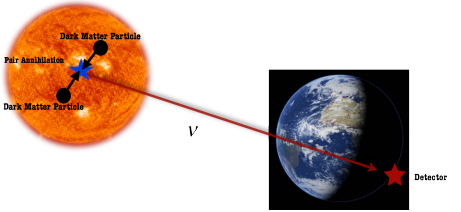
Detector Overview — Astrophysics/BSM Perspective

- Segmented plastic and scintillator tracking calorimeters
- Near: 300 t, underground
  - Small, low-background, exposed to high-energy cosmic muons
- Far: 14 kt, on *surface*
  - Large, high-background, exposed to low- and high-energy cosmic flux
- Primarily hydrocarbons
  - Plus 16% chlorine (PVC)



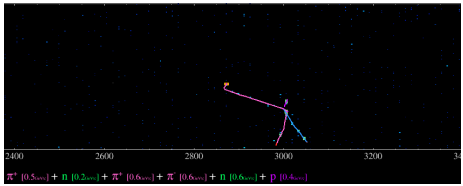
Far Detector: Dark Matter/$n\bar{n}$ Searches

DM search with upward-going muons



- Look for excess pointing back to Sun
- Perhaps sensitive to lower mass WIMPS than Super-K
- Dedicated trigger running since 2014

Neutron/anti-neutron oscillations

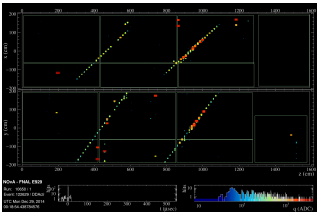


Simulated $\bar{n}$ annihilation in ^{12}C

- Suppressed in nuclei, less in C than O
- If low-background, might match Super-K with fewer kt-years
- Trigger running since 2018

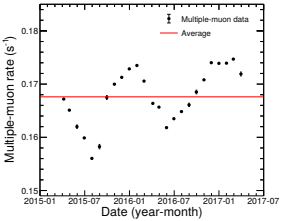
- Background levels not yet determined
- Limits $\propto$ exposure? $\sqrt{\text{exposure}}$?

Cosmic Ray Seasonal Variations



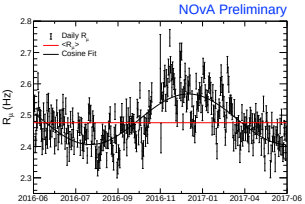
- Well-known summer maximum in underground muon rate
- NOvA observes winter maximum in multi-muons

- ND: PRD 99 **12**, 122004



- Origin unknown
- 2015/2016 difference in ND unexplained

- FD: analysis in progress

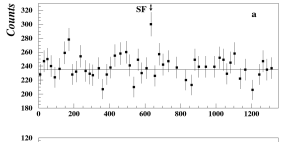


- Run through 2025 gives 8 additional annual cycles
- More cycles: more likely to disentangle complex effects

Other Cosmic Ray Studies

- Measurement of low-energy east-west asymmetry
- Short-term weather effects
  - Known, but understudied
- Solar flare correlation?
  - Claimed by L3+C
- Measure muon rates above 100 TeV
  - Resolve Baksan/IceCube discrepancy?

Most looking for rare effects, sensitivity will continue to rapidly improve with exposure



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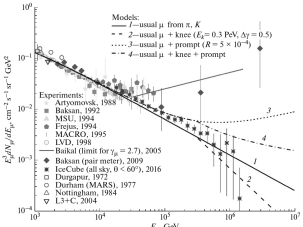

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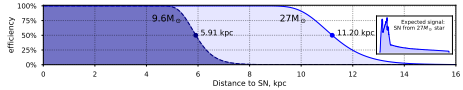
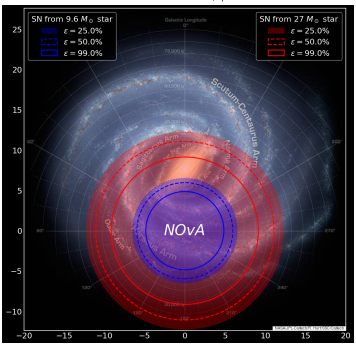
Supernova

- Self-trigger, covering half the galaxy
- SNEWS alerts cover the rest





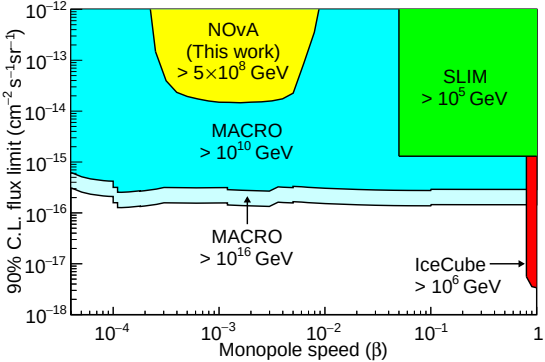
At Galactic center:

	Far	Near
$\bar{\nu}_e + p \rightarrow e^+ + n$	2163	46
$\nu_x + {}^{12}\mathrm{C} \rightarrow \nu_x + {}^{12}\mathrm{C}^*$	393	9
$\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$	137	3
$\bar{\nu}_e + {}^{12}\mathrm{C} \rightarrow e^+ + {}^{12}\mathrm{B}$	139	3
$\nu_x + e^- \rightarrow \nu_x + e^-$	199	4

- Largest operating carbon-based detector
- Different targets constrain flavor content
- Search for SN-like neutrinos with gravitational waves: PRD 101, **11** 112006
- Potential for supernova and exotic phenomena grow rapidly with exposure

Magnetic Monopole Search

- Far Detector: large surface area, minimal shielding
- Sensitive to light and/or slow monopoles that don't reach underground
- Separate search strategies for:
  - $\beta < 10^{-2}$: Select by timing. Analysis of 95-day exposure now on the arXiv: 2009.04867
  - $\beta > 10^{-2}$: Select by energy deposition. In progress.



- 1700 days of exposure already taken
- Background-free: limits scale linearly with exposure
- Expect to reach $4 \times 10^{-16}\,\mathrm{cm^{-2}s^{-1}sr^{-1}}$ for $3 \times 10^{-4} < \beta < 0.8$ by 2025

Summary

- NOvA has a rich program of BSM and cosmic-ray measurements
- Several improve proportional to exposure, making a long run beneficial:
  - Magnetic monopole search
  - Cosmic ray seasonal/short-term variation
  - High energy muon rate
  - Supernova
  - Gravitational wave follow-ups
  - Perhaps: dark matter, $n\bar{n}$ oscillation